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Nonlinear Pulsations of Luminous He Stars

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Abstract.

Radial pulsations in models of R Cor Bor stars and BD+1°4381 have been studied with a nonlinear hydrodynamic pulsation code. Comparisons are made with previous calculations and with observed light and velocity curves.

I. Introduction.

The R Cor Bor stars are characterized by atmospheres with extremely low hydrogen abundances, enhanced carbon, high luminosities ($10^4 L_{\odot}$) and effective temperatures of about 7000 K. At irregular intervals they show abrupt declines in brightness for several months that are attributed to the formation of a dust shell (Feast 1975). Many pulsate with small amplitudes and periods of 40 to 120 days (Saio 1986).

BD+1°4381 is also a hydrogen deficient star (Drilling 1979), with an effective temperature of 9500 ± 400 K (Drilling et al 1984), which was discovered by Jeffery and Malaney (1985) to pulsate with a 22 day period and an amplitude $\Delta V = 0.06$ magnitudes.

Linear non-adiabatic studies of luminous He stars have been done by Saio, Wheeler, and Cox (1984), Cox et al. (1980), Wood (1976), and Trimble (1972) among others. They find that the pulsations are very nonadiabatic, with the thermal timescales for such stars becoming comparable to the dynamic timescales. There is no longer a one to one correspondence between the adiabatic and non-adiabatic modes, new "strange" modes appear and modal identification

becomes difficult. Hydrodynamic models of luminous He stars have been studied by Trimble (1972), Wood (1976), King et al. (1980) and Saio and Wheeler (1982).

II. Models

We have calculated linear and hydrodynamic models for R Cor Bor stars, using the same parameters as Saio and Wheeler used for their models 7 and 8. We compare our results to theirs in table 1. The results of the two calculations are very similar, except that our linear growth rates are consistently about twice those obtained by Saio and Wheeler, and we get nonlinear amplitudes that are slightly larger. In addition to the modes discussed by Saio and Wheeler we also list the closest adjacent modes that we found in our linear analysis. Because of the complexity of the modal structure for these stars we do not attempt to identify the adiabatic counterparts of these modes.

In addition to using a composition of 90% helium and 10% carbon by mass, we also computed linear models using a mixture with 98% helium and 2% metals in solar proportions. These mixtures are designated "he9c1" and "cxhdsn2a" on the Los Alamos opacity tables. The best abundance analysis of R Cor Bor suggests that carbon is about 1.2% of the mass of the atmosphere, with nitrogen and oxygen in approximately solar abundances (Cottrell and Lambert 1982). So the appropriate opacity to use is probably intermediate between these two mixtures. The models with lower metal abundance tend to have smaller linear growth rates, but numerical difficulties have so far prevented calculation of nonlinear models with these opacities. Since the models with 10% carbon show nonlinear amplitudes significantly larger than actual R Cor Bor stars, nonlinear models with appropriate compositions should be calculated.

Our nonlinear models show a double periodicity, with alternate cycles having larger amplitudes. We attribute this to the presence, with a small amplitude, of a higher order mode. Our linear models show such a mode, with a period close to two thirds of the period of the dominant mode. We do not know if this mode is locked into a resonance with the dominant mode or if it will damp out after a large number of periods. While the light and velocity curves of R Cor Bor stars are observed to vary from cycle to cycle, there has been no suggestion of this kind of double periodicity being observed in high luminosity He stars.

Schönberner (1979) calculated models of He shell burning stars with a CO core and a thin He envelope in the range of 0.7 to 1.0 M_{\odot} . Stars with the same total mass but with a smaller core mass could have lower luminosities than these models, but it would be difficult for a star

of the same mass to have a higher luminosity. If we assume a M-L relation for BD+1°4381 consistent with Schönberner's models and a T_{eff} of 9500 K, we find a pulsationally unstable mode with the observed period of 22 days if we use a mass of $0.95M_{\odot}$ (See table 2). For lower masses the longest pulsationally unstable mode that we find has too short a period, unless we assume a luminosity higher than consistent with Schönberner's models. Our models show very high linear growth rates and large nonlinear amplitudes (see table 2). As with our R Cor Bor models a lower metal abundance has a strong effect on the growth rates of the pulsational modes and there is a 2:3 period ratio between the 22 day mode and a higher order mode that results in a double periodicity in the light curve. Published light curves of BD+1°4381 are not detailed enough to show whether or not such behavior is actually present.

Such a large mass and high luminosity seems inconsistent with BD+1°4381's location about 25° below the galactic plane. It would require a very large error in the measured effective temperature to reduce this mass significantly. An effective temperature of about 8000 K is needed for a $0.7M_{\odot}$ star with the luminosity of Schönberner's model to have a unstable mode with a period near 22 days.

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Table 1

| | $0.9M_{\odot}$ | $17000L_{\odot}$ | 7100 K | |
|------------------|--------------------|------------------|----------|--|
| | $P_L(\text{days})$ | η | Comp | |
| This Paper | 72.2 | -2.8 | He9C1 | |
| " | 32.6 | +1.9 | " | |
| " | 21.0 | -0.002 | " | |
| Saio and Wheeler | 32.9 | +1.0 | He9C1 | |
| This Paper | 75.8 | -2.3 | Cxhdsn2a | |
| " | 37.0 | -0.57 | " | |
| " | 20.0 | -0.60 | " | |

| | $P_{NL}(\text{days})$ | $\Delta v(\text{km/sec})$ | ΔM_{bol} | Comp |
|------------------|-----------------------|---------------------------|------------------|-------|
| This Paper | 37 | 55 | 1.4 | He9C1 |
| Saio and Wheeler | 37 | 46 | 1.2 | He9C1 |

| | $0.7M_{\odot}$ | $15000L_{\odot}$ | 7000 K | |
|------------------|--------------------|------------------|----------|--|
| | $P_L(\text{days})$ | η | Comp | |
| This Paper | 64.1 | -1.5 | He9C1 | |
| " | 35.8 | +2.9 | " | |
| " | 23.5 | -1.1 | " | |
| Saio and Wheeler | 36.2 | +1.4 | He9C1 | |
| This Paper | 64.2 | -1.1 | Cxhdsn2a | |
| " | 38.7 | +2.1 | " | |
| " | 22.9 | -0.1 | " | |

| | $P_{NL}(\text{days})$ | $\Delta v(\text{km/sec})$ | ΔM_{bol} | Comp |
|------------------|-----------------------|---------------------------|------------------|-------|
| This Paper | 41 | 46 | 1.2 | He9C1 |
| Saio and Wheeler | 42 | 40 | 1.0 | He9C1 |

Table 2

| | $0.95M_{\odot}$ | $33000L_{\odot}$ | 9500 K |
|--|-----------------|------------------|--------------------|
| | P_L | η | comp |
| | 39.1 | -0.63 | H ₂ 9C1 |
| | 21.7 | +0.51 | " |
| | 14.3 | +0.05 | " |
| | 42.0 | -0.53 | Cxhdsn2a |
| | 18.9 | +0.92 | " |
| | 14.6 | +2.1 | " |

$$P_{NL} = 21.4 \text{ days} \quad \Delta M_{bol} = 0.6 \quad \Delta v = 65 \text{ km/sec}$$

Observed values for BD+1°4381 are $P = 22$ days, and $\Delta V = 0.06$.